Introduction

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COURSE DESCRIPTION

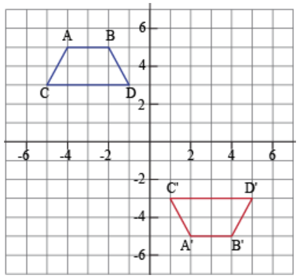
Course Brief

Introduces the students to the amazing world of interactive 3D graphics for computer games, virtual/mixed reality and photorealistic production rendering.

We examine state-of-the-art CGI pipelines and established algorithms along with examples of proven commercial systems. The course addresses techniques such as deferred and tile-based rendering, real-time global illumination, real-time visual effects and ray-tracing-based methods for offline and real-time image synthesis.

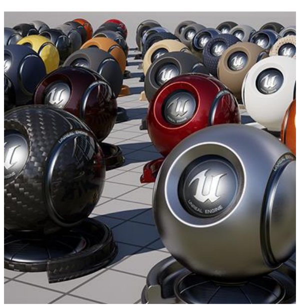
Course Contents (1)

Computer Graphics Foundations (BSc Recap)



Introduction to computer graphics. Basic concepts, tools, applications, and production pipelines. Surface representations and data primitives and organization. Coordinate systems, geometric transformations, viewing and projections.

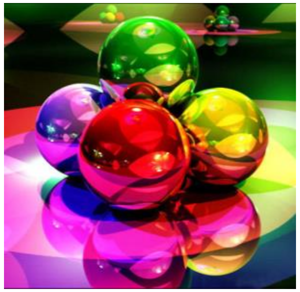
Real-time graphics – The rasterization pipeline. The hardware rasterization graphics pipeline: stages, polygon clipping and sampling, the graphics processing unit (GPU), programmable stages and image composition. Aliasing and antialiasing.



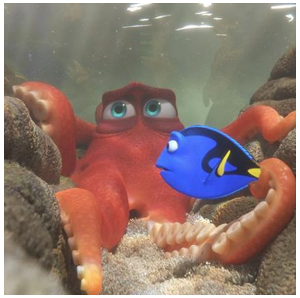
Appearance and shading. Materials and surface properties, local shading models (overview) and their properties, basic radiometric properties and the reflectance equation. Texturing and texture maps.

Course Contents (2)

Production Rendering



Ray tracing. The ray tracing pipeline, applications, pros and cons, ray generation, scene traversal and acceleration structures, specular reflection and transmission. Comparative study vs rasterization.



Light transport theory and stochastic path tracing. The rendering equation, approximations and Monte Carlo integration. Modelling of arbitrary light sources and global illumination via path tracing. Overview of path tracing-based methods: bidirectional path tracing, photon mapping, Metropolis light transport. Distribution effects.

Volume Graphics. Principles of light transport in participating media, volume rendering techniques, real-time volumetric visualization, applications to medical imaging and scientific visualization.

Course Contents (3)

Production Rendering

Real-time graphics – computer game graphics. Real-time shading pipelines, order-independent transparency, multi-pass algorithms: shadow generation, illumination caching, environment mapping and introduction to real-time global illumination techniques. Post-processing effects for games.

Virtual and Mixed Reality. Introduction to stereo rendering, immersion, technologies and systems for VR interaction. AR: principles and technologies. Interaction metaphors for VR.

Animation and Motion Capture. Principles and theory of basic computer animation, motion capture and tracking techniques and technologies, real-time animation concepts and implementation.

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Grading

Option	Written exam	In-depth survey	Project	Details
Normie	7/10		3/10	Regular project, programming language of choice (C++ preferred)
Code junkie	5/10		5/10	Implementation of a core graphics algorithm in C++. Path tracing or VR options (with Oculus Rift) available.
The Nerd	5/10	5/10		Survey of methods or technology with comparative study, implementation difficulties, performance analysis and extensive references.
The “writer”	10/10			No surveys, no projects, just plain ole exams, for those who are not so comfortable with their programming or research skills.

Course Material - Textbook

- Main textbook: Graphics and Visualization: Principles & Algorithms, T. Theoharis, G. Papaioannou, N. Platis, N. M. Patrikalakis, AK Peters, USA, 2008
- Also available in Greek: Γραφικά και Οπτικοποίηση: Αρχές & Αλγόριθμοι, εκδόσεις ΣΥΜΜΕΤΡΙΑ.
- Additional lecture notes and slides on the e-class platform.
- Covers ~85% of the course topics

- Additional lecture notes on VR by Steven M. can be found at http://msl.cs.uiuc.edu/vr/ .

Course Material – Presentation Slides

- Additional lecture notes and slides on the e-class platform
- Note: Stay calm and breathe normally. For completeness, most of the slides provide a deeper analysis of the topics covered than it is required for the level of the course
- Students are not required to study the entirety of the material provided (though they are most welcome to do so)

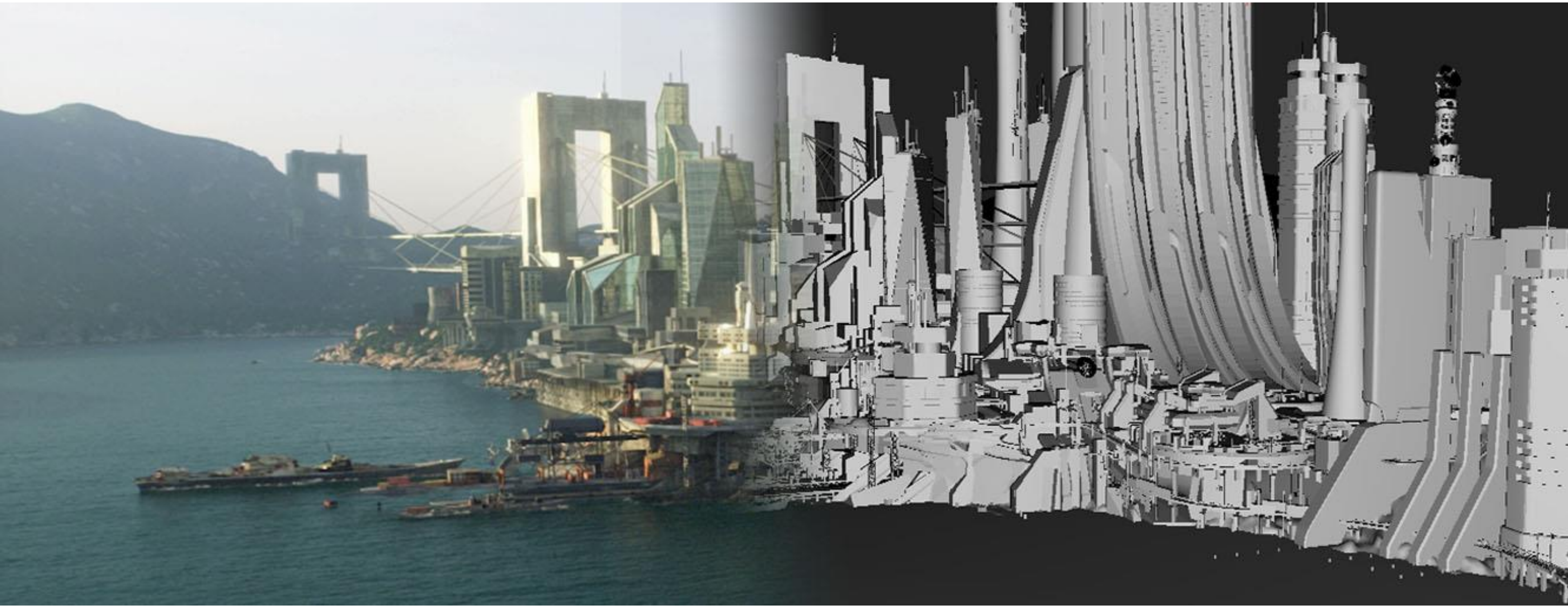
Course Material – Suggested Reading

- Real-Time Rendering, Third Edition, T. Akenine-Möller, E. Haines, N. Hoffman, CRC Press, 2008 (new edition coming Q2 2018).
- Physically Based Rendering: From Theory to Implementation, Matt Pharr, Wenzel Jakob, Greg Humphreys, 3rd Edition, Morgan Kaufmann, 2016.

BASIC CONCEPTS

Image Synthesis

Image Synthesis



Educational Goals

- Learn about image synthesis techniques and algorithms
- Find out how image synthesis is applied to common tasks and applications
- Learn how to develop applications using computer graphics (BSc)
- Find out how complex imagery is created (MSc)

Prerequisites

- Basic linear algebra and calculus
- Basic understanding of computing architectures
- Basic programming skills (preferably in C/C++)

MSc:

- Elements of probability theory
- Basic linear algebra and calculus
- A plus, but not mandatory:
  - Undergraduate course in CG

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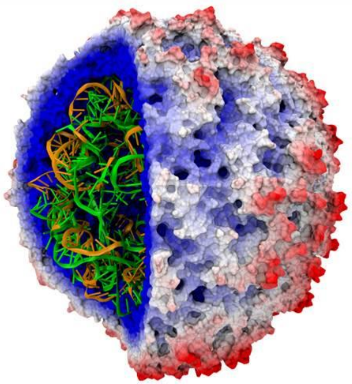
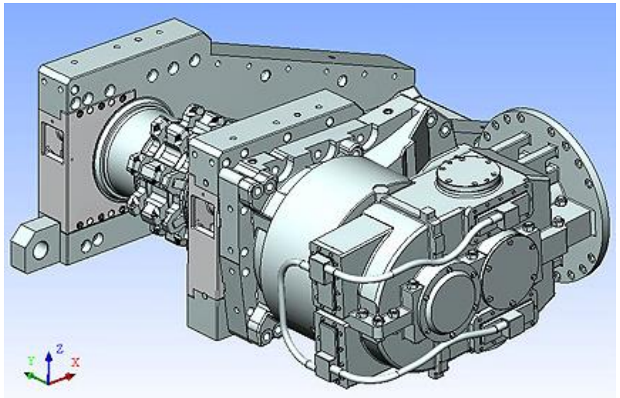
What do we use CG for?






CG Applications

- Computer games and interactive applications
  - Most high-efficiency algorithms come from and target this application domain!
  - Big industry, from indy and casual games to AAA productions
- Computer-Aided Design / Manufacturing / Engineering
  - Physical product design using surface and solid modeling and geometric tools
- GUIs
  - 2D GUI implementation and acceleration
  - VR / AR and human-friendly interactive systems

CG Applications

- Special effects for feature films
  - Ability to create the impossible or non-existent
- Animated films
- Scientific and medical visualization
- 2D and 3D printing technology

DEFINITIONS

Rendering

- Rendering is the process of generating an image from a set of models (geometric representation)
  - It is the final product of a general image synthesis task using a rendering pipeline

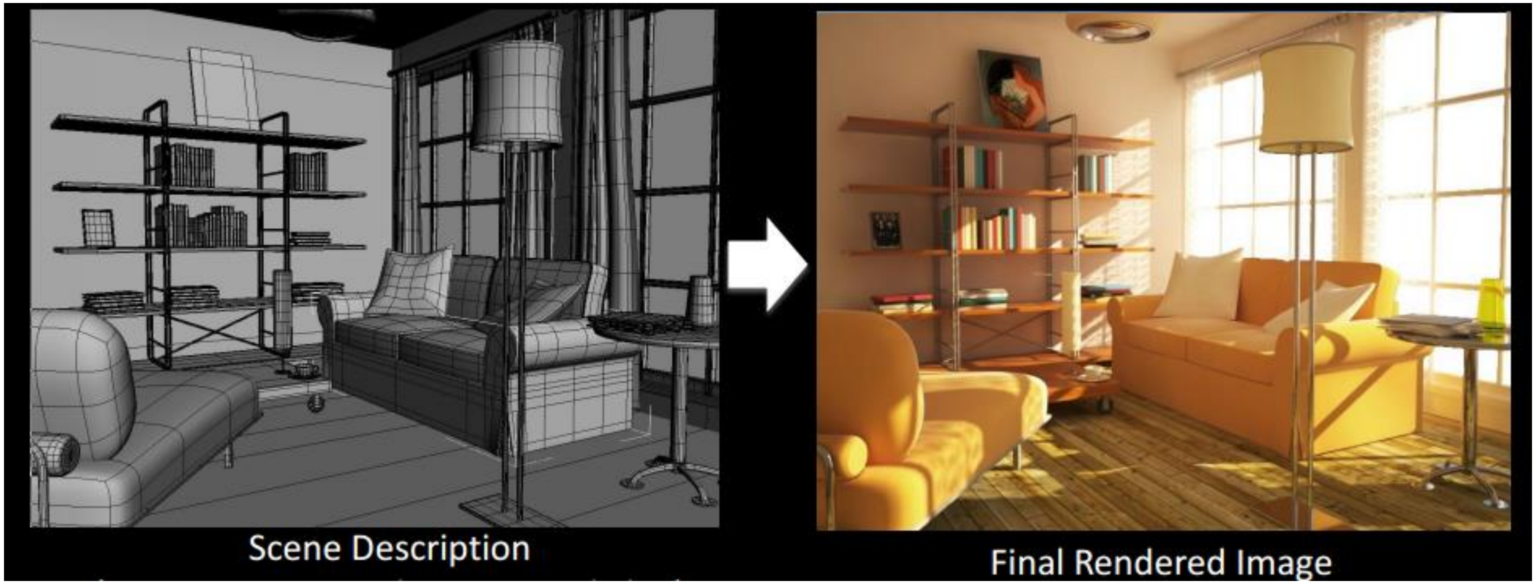
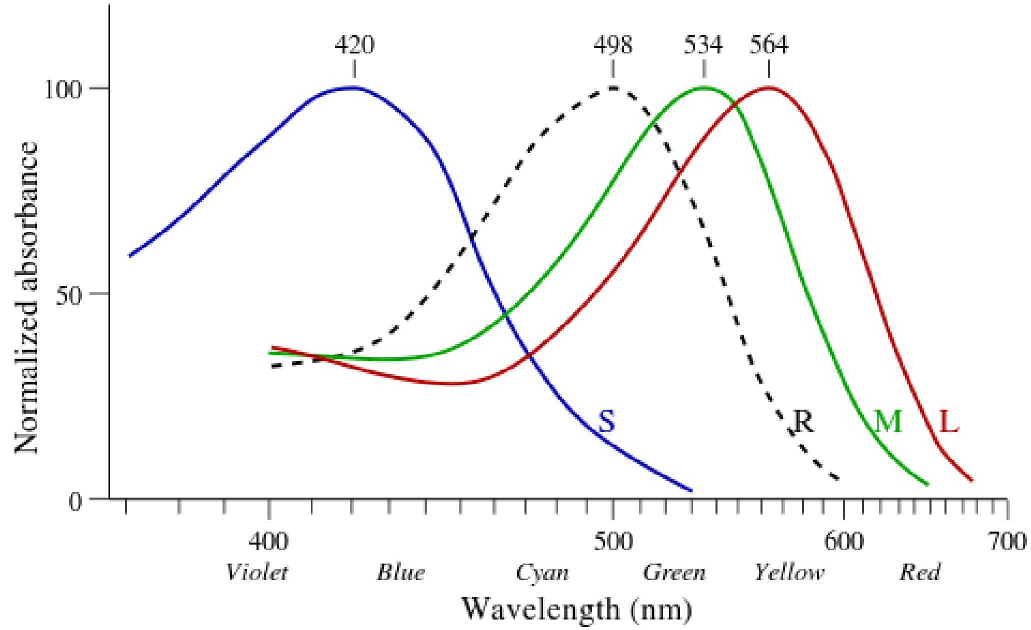


Image credit: http://alex-mccarthy.blogspot.com

The Human Visual System

- Sensitive photoreceptors: Rodes and Cones
- The human visual system adapts to the level of illumination incident to the photoreceptors
  - Rods (scotoptic light): $10^{-6}cd/m^2 – 10cd/m^2$
  - Cones (photoptic light): $10^{-2}cd/m^2 – 10^8 cd/m^2$
- Total luminance range: $10^8:10^{-6}$

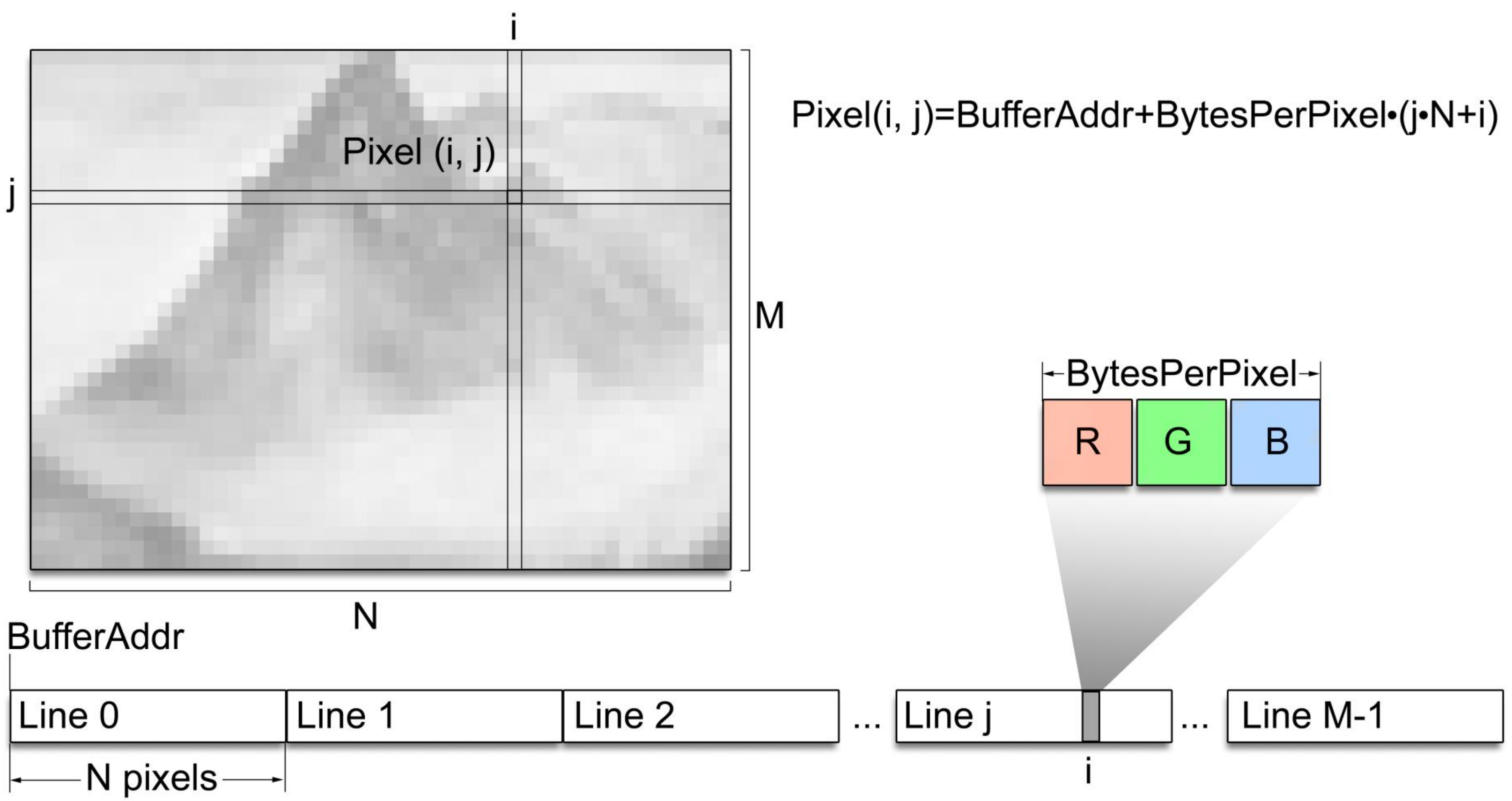


The Digital Image

- A discretized configuration of intensity samples
- Usually an array of pixels (a *raster*)
  - Discrete approximation of a 2D continuous signal
  - Luminance is sampled using a fixed or variable rate and attributed to the neighborhood of each pixel
- Image color data are represented using a color model
  - RGB (compatible with HVS)
  - Other (see Color chapter)
- Storage:
  - Separate color channels per pixel

Image – Storage

- Typically stored as an array in memory
- Interleaved color channels
- Line/column configuration, but also in blocks



Dynamic Range

- Dynamic range: the minimum to maximum luminance level achieved by a system
- HVS range: $10^8:10^{-6}$
- H/W cannot achieve these levels simultaneously!
  - We use *tone mapping* to adjust the “useful” range to match the output range of a device
- Physically measured or simulated radiance (therefore luminance) in a natural environment matches the HVS levels
- Typical displays can achieve a **dynamic contrast ratio** of 6000:1 and an **actual luminance level** of 1-300cd/m^2

High Dynamic Range Images

- Use floating point arithmetic representation to store a wide range of luminance values
- Used both in CG and photography
- Typical integer buffers and image formats (8 bits per color channel) are not enough
- Precision depends on storage limitations and application: unsigned bytes: 24bit color, floating point (half/full): 48/96bit images
- HDR screens use a combination of 8bpp panels and temporal dithering to increase the perceived levels.

The Frame Buffer

- The area of memory that stores the resulting pixels/fragments during rendering.
- Can either represent:
  - The final displayed frame
  - Intermediate results, later to be used as textures

Intermediate Frame Buffer (render-to-texture)

Final Frame Buffer with Color Grading

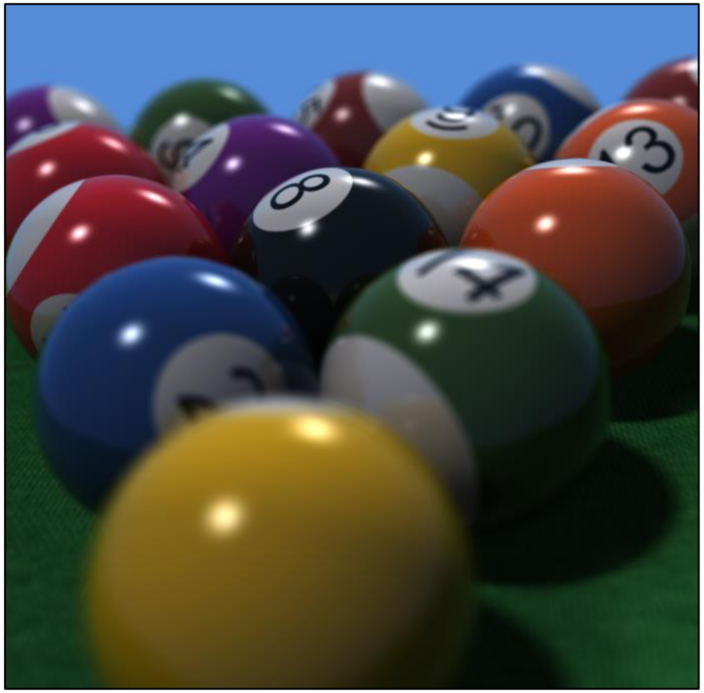
Offline and Real-time Rendering

- Offline Rendering
  - Quality is fixed, time is negotiable
  - No Artifacts (AA, motion blur, smooth surfaces etc)
  - Want < 1min per frame, can accept 10-12 hours
  - Typical machine: *render farm* (computing cluster)
- Real-time Rendering
  - Time is fixed, quality is negotiable
  - Many artifacts (aliasing, poor lighting)
  - Max bound: ~16 ms (60 fps),
  - Can accept ~50 ms (20 fps)
  - Typical machine: commodity hardware (GPUs), game consoles, mobile devices

Where is the Borderline?

- Increasingly fast GPUs and the many-core implementation of "traditionally" offline algorithms blur the border
- Still, physically correct and high quality rendering of complex environments are offline

Computer game (Unity 5 demo - 2016)



Real-time ray tracing of a simple scene

What About 2D Rendering?

- Today, most hardware-accelerated 2D drawing is handled via the 3D h/w pipeline!
  - Textured polygons and framebuffers for views and bitmap storage: fast access and redraw, easy transitions and effects
  - Blending and widget ordering handled by the hidden surface removal and blending of the GPU
  - Shape rasterization and fills via GPU rasterization

Graphics Pipelines

- "Graphics Pipeline" is the sequence of steps that we use to create the final image
- Many graphics/rendering pipelines have been proposed

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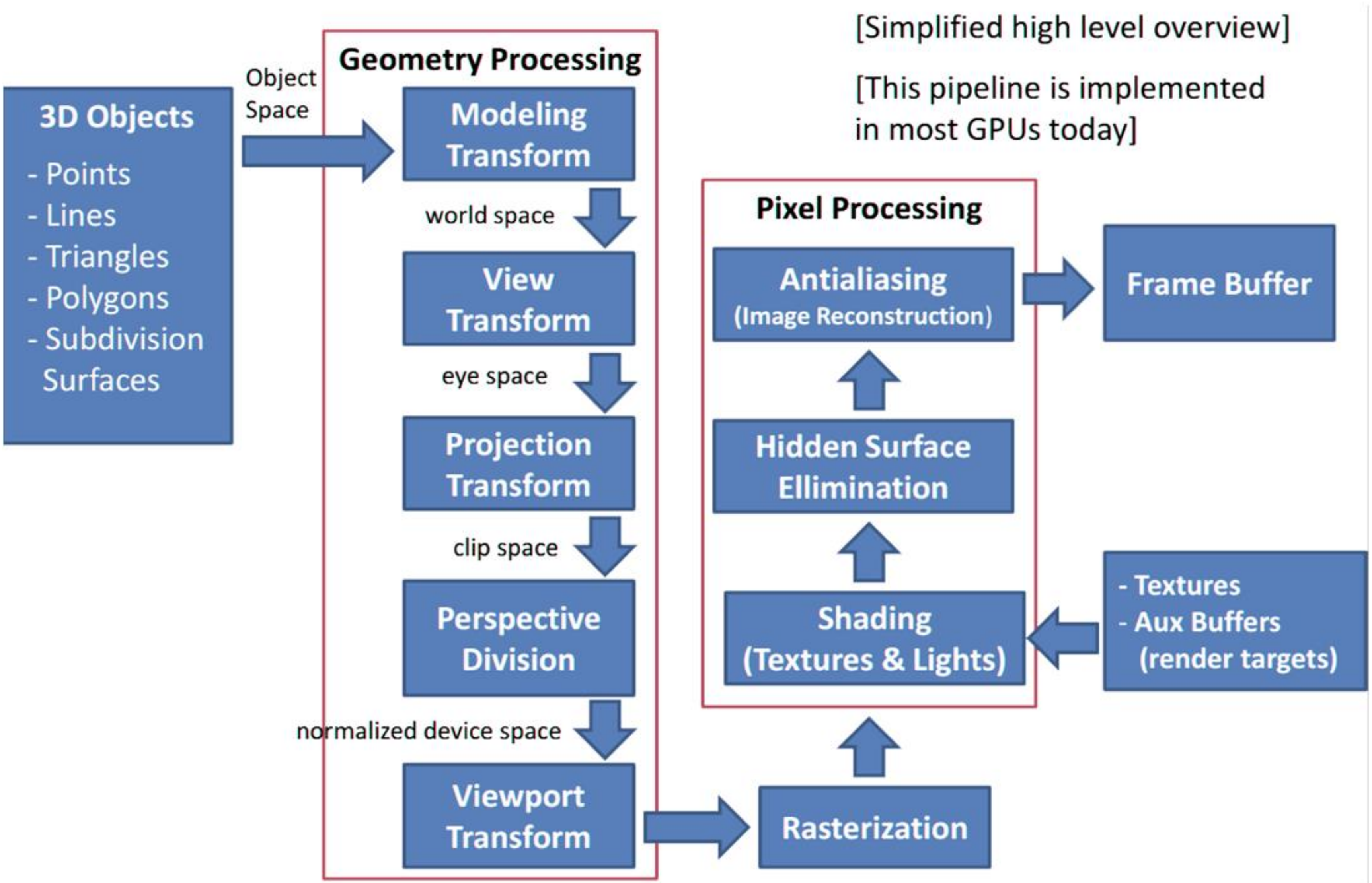
Graphics Pipelines (2)

- Scanline- / Rasterization-based
  - Immediate Direct rendering, Tile-Based, Deferred Rendering, 2D shape rasterization (windowing systems, GUIs)
  - Used mainly for real-time rendering (GPUs)
- Micropolygon-based Reyes (e.g. old Pixar’s Renderman)
- Ray Tracing-based
  - Path tracing, photon mapping, bidirectional path tracing etc.
  - Used for advanced lighting simulations

GPU Rasterization Pipeline



Contributors

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